CHARACTERISTICS OF THE SULUKNA RIVER SPAWNING POPULATION OF INCONNU, YUKON RIVER DRAINAGE, ALASKA

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A

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Abstract

Inconnu *Stenodus leucichthys* are large migratory whitefish harvested in subsistence and sport fisheries in Alaska. Research on the Sulukna River spawning population of inconnu was conducted in September and early October from 2007 to 2009. Samples were collected to verify maturity and spawning readiness, and to determine age distributions of mature males and females. Spawning abundance was estimated and post-spawning migration timing was identified. Otoliths were analyzed optically to determine age and chemically to determine amphidromy. Maturity sampling indicated that all sampled fish were in spawning condition or had recently spawned. Abundance estimates were 2,079 and 3,531 inconnu in 2008 and 2009, respectively. Post-spawning downstream migration timing was nearly identical between years, with the majority of fish moving downstream between September 30 and October 9. In both years, migrating inconnu displayed a nocturnal migration pattern, with 96% migrating between 2000 and 0900 hours daily. Age estimates ranged between 6 and 26 years. Chemical analysis indicated that some Sulukna River inconnu were amphidromous, making migrations of over 1,300 km to the sea. This information indicates that the Sulukna River spawning population of inconnu has a large and variable abundance, in which amphidromy is facultative.

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1.0 General introduction

1.1 Background

Inconnu *Stenodus leucichthys* are the largest whitefish species of the family Salmonidae, subfamily Coregoninae. Individuals can live over thirty years and attain weights up to 40 kg (Wynn-Edwards 1952; Howland 1997; VanGerwen-Toyne et al. 2008). Inconnu have a circumpolar distribution within Arctic and sub-arctic river systems in Eurasia and North America. In Eurasia, they range from Kamchatka westward across Siberia to the White Sea, with another sub-species (*S.l. leucichthys*) present in the Caspian Sea (Morrow 1980). In Alaska, inconnu are found in the Kuskokwim, Yukon, Selawik, and Kobuk river drainages (Morrow 1980). Within Canada, inconnu are found in the upper Yukon River, the Anderson River, and the Mackenzie River system, including Great Slave Lake and its tributaries (Scott and Crossman 1973).

Inconnu are an important fishery resource wherever they occur (Petrova 1976; Anderson et al. 2004; Brown et al. 2005). In the Irtysh River basin in Siberia, commercial catches have exceeded 600,000 pounds annually (Petrova 1976) and subsistence catches in the Kobuk River in northwestern Alaska have exceeded 30,000 fish annually (Alt 1969b). The opportunity to catch inconnu year round in northwestern Alaska is thought to make them susceptible to over-fishing (Banducci et al. 2007). Commercial fishing and dam construction in some Eurasian rivers have resulted in lower abundances, a change in the age and size structure of the population, and the extirpation of some spawning populations (Petrova 1976; Chereshnev et al. 2000). Data regarding the abundance, age and size composition, and migratory patterns of Alaskan inconnu populations must be obtained if we are to evaluate the impacts of fisheries and development activities in Alaska.

1.2 Life history

Inconnu are a highly migratory species with life history strategies that can be either amphidromous, fishes whose migration from fresh water to sea is not for the purpose of breeding but occurs regularly at some other definite stage of the life, or potamodromous, truly migratory fishes whose migrations occur wholly within fresh water (Myers 1949). Inconnu populations differ in the degree of amphidromy exhibited by populations. The Mackenzie River system (Northwest Territories, Canada) has both amphidromous (Arctic Red River) and potamodromous (Slave River) spawning populations (Howland et al. 2001). Individuals from the Tanana River population have exhibited both life history strategies (Brown et al. 2007). These migrations occur on an annual basis. Inconnu feed and overwinter in the lower reaches of large rivers (Alt 1977). Upstream migrations from overwintering habitats to freshwater feeding habitats begins in April and May under the ice, and includes fish that will spawn in the fall and those that will not (Alt 1977). For spawning fish, migration to spawning areas can take from several weeks to months depending on the distance from feeding and overwintering areas (Howland et al. 2000). Inconnu have been documented moving at a rate of 8 to 13 km/d in the Anadyr basin in Russia (Chereshnev et al. 2000) and 21 to 26 km/d in the Yukon River in Alaska (Brown 2000). These migrations have been documented to be in excess of 1,800 km in some cases (Stephenson et al. 2005).

Inconnu spawn in late September and early October (Alt 1988). Most inconnu mature by ages 8 to 12 (Brown 2000), with males generally maturing before females and potamodromous populations maturing earlier than amphidromous populations (Howland 2005). Spawning frequency was thought to be on an every other year or greater basis (Alt 1969a; Reist and Bond 1988; Taube 1997). However, some populations exhibit high frequencies of fish that spawn in sequential years with males being more likely to be repeat spawners (Hander et al. 2008). Inconnu are iteroparous broadcast spawners that spawn in streams with substrates composed of different sizes of gravel (Morrow 1980). Inconnu spawn at night, favoring water temperatures ranging from 1.4° to 4.6°C (Morrow

1980; Gerken 2009). Absolute fecundity of female inconnu varies from 80,000 to 420,000 eggs (Chereshnev et al. 2000). Once spawning is completed, post-spawn inconnu begin a rapid migration downstream to overwintering areas (Fuller 1955; Howland et al. 2000). Inconnu eggs hatch in spring and larvae are thought to be displaced downstream by spring floods (Reist and Bond 1988).

As inconnu mature from juvenile to the adult life stages there is a transition in diet and feeding patterns. Juvenile inconnu feed first on zooplankton and transition to other invertebrates before shifting to a primarily piscivorous diet as they mature (Fuller 1955; Morrow 1980). As adults inconnu have been shown to feed intensively in winter (Petrova 1976), with little feeding immediately prior to spawning (Brown 2000).

1.3 Yukon River inconnu

Inconnu in the Yukon River drainage are seasonally distributed throughout the watershed. Individuals are harvested year round throughout their distribution primarily for subsistence purposes (Anderson et al. 2004; Brown et al. 2005). In the Yukon River watershed, only five inconnu spawning areas have been identified in Alaska: the upper Koyukuk River (Alt 1969a), the Alatna River (Alt 1969a), the mainstem of the Yukon River between the villages of Ft. Yukon and Circle (Brown 2000), the Chatanika River (Alt 1969a), and the Sulukna River (Alt 1985). Of these five spawning populations only the mainstem Yukon River population has been studied extensively. This population has mature individuals that range from 7 to 28 years in age and are amphidromous making migrations of over 1,700 river km (rkm) from spawning locations to the sea (Brown 2000).

1.4 Study objectives

This thesis details research conducted between 2007 and 2009 on a population of inconnu that spawn in the Sulukna River, a tributary of the Nowitna River. The main objectives were: (1) estimate the abundance of post-spawning migrating inconnu; (2) determine the timing of the migration; (3) estimate the size and age composition of the spawning population; and (4) determine if individuals from this population were migrating to marine environments. Dual frequency identification sonar was used to estimate abundance and determine migration timing. Sampling data were used to estimate length and age distributions of the spawning population. Sagittal otoliths were prepared initially for aging, and chemical analyses of a subsample of otoliths were used to identify the occurrence of amphidromy.

1.5 Study area

The Sulukna River flows north for approximately 180 rkm from its origin in the Sischu Mountains to its confluence with the Nowitna River. The watershed drains an area of approximately 1,772 km^2, and is relatively unaltered by human disturbance. The Sulukna River study site (Latitude 64.10104 N, Longitude 154.02997 W) was located 30 rkm upstream from its confluence with the Nowitna River (Figure 1.1). Inconnu are known to spawn in a 20-km reach located between rkm 72 and 92 (Gerken 2009). The lower Sulukna River, below rkm 60, is a low-gradient sinuous river with gravel as its dominant substrate (Gerken 2009). The river typically freezes between mid-October and early November and remains ice covered until the following May. It is tannin stained in summer, but runs clear in late fall and winter. Water characteristics, such as pH, conductivity, total hardness, and alkalinity, are higher than in other tributaries of the Nowitna River (Mueller et al. 1996). The U.S. Fish and Wildlife Service (USFWS), Nowitna National Wildlife Refuge, manages the Sulukna River watershed downstream from approximately rkm 15, and the Bureau of Land Management (BLM) manages the remainder of the river. In 1986, a portion of BLM lands within the watershed was designated as an Area of Critical Environmental Concern due to the high value of the inconnu spawning habitat (BLM 1986).

The Sulukna River contains spawning populations of Chinook *Oncorhynchus tshawytscha* and coho *O.kisutch* salmon, with chum salmon *O. keta* also present. Resident fish species in the Sulukna River include Arctic grayling *Thymallus arcticus*, northern pike *Esox lucius*, longnose sucker *Catostomus catostomus*, slimy sculpin *Cottus* *cognatus*, round whitefish *Prosopium cylindraceum*, Alaska blackfish *Dallia pectoralis*, and humpback whitefish *Coregonus pidschian*.

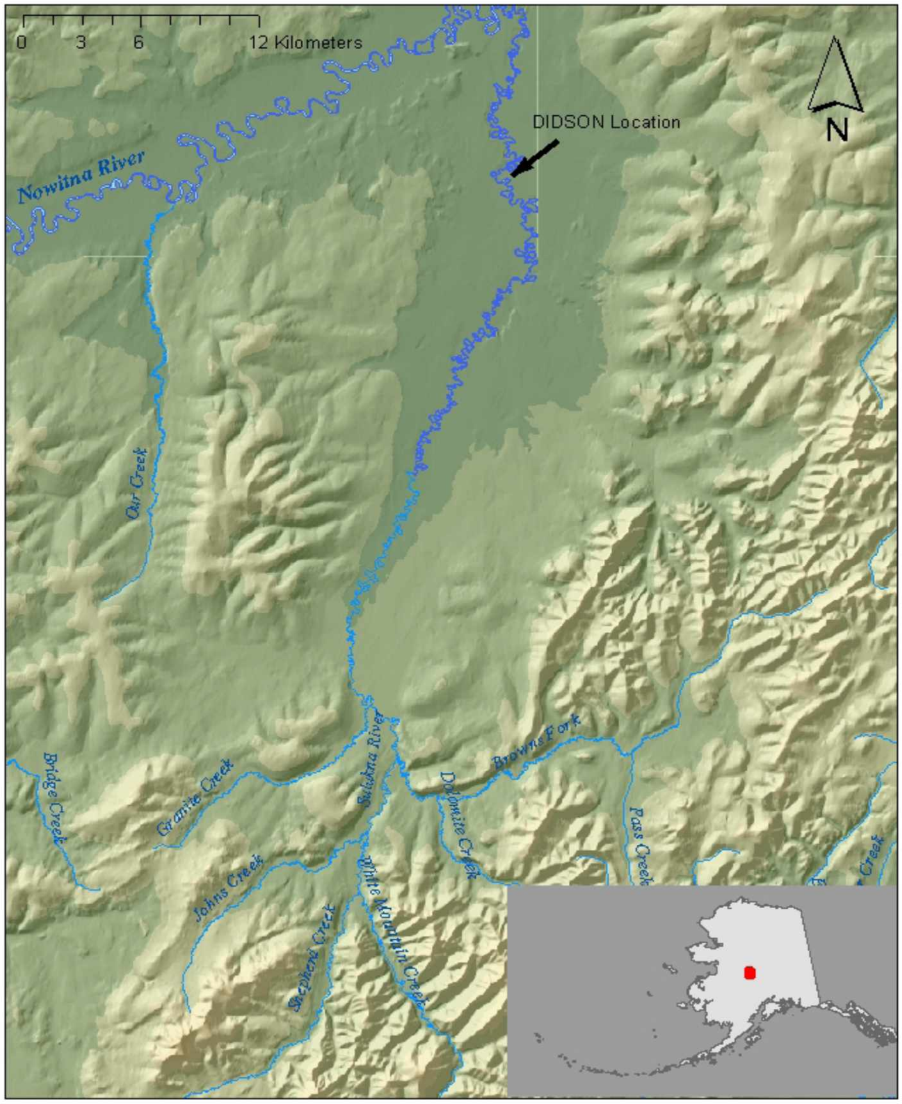

Figure 1.1 Study site on the Sulukna River, Alaska.

2.0 Biological sampling, otolith aging, and chemical analysis

2.1 Introduction

2.1.1 Length, weight, age, and feeding

Determining which spawning population sampled fish belong to is a critical first step in the study and management of fish species. Inconnu appear to exhibit high spawning fidelity to their natal river (Taube and Wuttig 1998; Hander et al. 2008). There are five known spawning populations of inconnu within the Yukon River watershed (Alt 1969a, 1985; Brown 2000). Individuals from these spawning populations intermix within overwintering and feeding areas (Brown 2000). In late spring and early summer, inconnu move from these areas to locations where spawning occurs in fall (Alt 1977). Collecting inconnu adjacent to their spawning locations gives mangers stock-specific data regarding their migration, age composition, size, and abundance with which to better manage the species (Taube 1996, 1997; Taube and Wuttig 1998; Brown 2000; Hander et al. 2008).

Correctly identifying if fish collected are in spawning readiness is important when studying a spawning population. To ensure that inconnu sampled are part of a spawning population, several techniques have been developed. When handling inconnu, the release of eggs or milt has been used to indicate that an inconnu is in spawning condition (Gerken 2009). Several studies within the Yukon River on spawning populations demonstrated that lack of feeding can be used as an additional indicator of spawning condition. Alt (1969a) found that pre-spawning inconnu did not feed for weeks prior to spawning. Brown (2000) found that over 99% of the pre-spawning inconnu sampled had no food in their stomachs. The use of these two methods can ensure that sampled individuals are part of the Sulukna River spawning population.

Otoliths of teleost fishes are paired structures of the inner ear whose primary function is the detection of sound and balance (Degens et al. 1969). They are primarily composed of calcium carbonate and a protein matrix (Degens et al. 1969) that is deposited in layers as the fish grows (Mugiya 1964). These layers appear as rings, which can be used to determine the age of the fish and their growth history (Tzeng 1990; Tzeng and Tsai 1992). The width of these rings is thought to be related to changes in deposition rates during alternating periods of fast and slow growth (DeVries and Frie 1996). Otoliths do not undergo resorption (Campana and Neilson 1985) and therefore, unlike scales, can be used for the aging of long lived fishes (Taube and Wuttig 1998; Howland et al. 2004).

2.1.2 Otolith chemistry

As the otolith is formed, calcium (Ca) and trace elements such as strontium (Sr) are incorporated into the otolith's matrix from the water in which the fish lives (Degens et al. 1969). Strontium commonly replaces Ca within the otolith because of their similar ionic radius and valence (Amiel et al. 1973). The Sr concentration of seawater increases in direct proportion to its salinity (Ingram and Sloan 1992), ranging from 0.06 mg/L Sr in fresh water to 8.0 mg/L Sr in sea water (Rosenthal et al. 1970). The amount of Sr in the otoliths is a reflection of the water in which the fish lives, with higher Sr concentration water resulting in higher Sr levels within the otoliths (Radtke 1989; Secor 1992). It has been suggested that otolith Sr is better correlated to water Sr:Ca (molar) than water Sr, primarily because of the competitive nature of the precipitation of Sr in the presence of Ca ions (Campana 1999).

Scientists have analyzed patterns of otolith Sr distribution to determine if fish captured in fresh water had encountered estuarine or marine environments (Radtke 1989; Kalish 1990; Secor 1992). A wide variety of techniques and technologies have been used for chemical analysis of otoliths including laser ablation – inductively coupled plasma mass spectrometry (Fowler et al. 1995); micro-proton induced X-ray emission (Babaluk et al. 2002); and electron microprobes (Campana et al. 1997; Howland 1997; Brown 2000). The wavelength dispersive electron microprobe (WD-EM) is capable of measuring Sr concentration on a small spatial scale (Gunn et al. 1992; Campana et al. 1997). The WD-EM operates by focusing an electron beam onto a sample surface, which results in atoms being ionized and X-rays being released. Each element has characteristic X-rays which are counted by spectrometers tuned to the appropriate wavelength. These

X-ray counts are proportional to the elemental concentration in the sample (Reed 1997; Goldstein et al. 2003). These Sr concentration data, in conjunction with age data, can then be used to determine whether a fish has migrated to saltwater areas and indicate the age at which this migration occurred (Brown 2000; Howland et al. 2001).

Prior to the existence of chemical analysis of otoliths, determination of amphidromy of inconnu within North America was ascertained primarily through tagging (Alt 1968, 1977) and telemetry studies (Alt 1975). Chemical analysis has proven that migrations of inconnu were longer than previously documented, with some individuals making migrations of up to 1,800 km in the Mackenzie River, Canada (Stephenson et al. 2005), and 1,700 km in the Yukon River, Alaska (Brown et al. 2007). Within Alaska, the upper Yukon River spawning population has been categorized as amphidromous, with all individuals sampled revealing signs of amphidromy (Brown 2000). Amphidromous inconnu were also found distributed throughout the Yukon, Koyukuk, and Tanana rivers (Brown et al. 2007). Canada's Mackenzie River has spawning populations of inconnu that are both non-amphidromous (Slave River) and amphidromous (Arctic Red River) (Howland et al. 2001). Amphidromous individuals were also found in the Liard River (Stephenson et al. 2005).

This chapter describes the aging and chemical analysis of otoliths collected from the Sulukna River's spawning population of inconnu. The primary objectives were to determine if sampled individuals from the Sulukna River population were migrating to salt water areas and at what age. The secondary objectives were to determine the length, weight, feeding habits, and age composition of the sampled inconnu.

2.2 Methods

2.2.1 Length, weight, age, and feeding

I sampled inconnu from three locations in the Sulukna River during the course of this study. Prior to sampling, a University of Alaska Fairbanks Institutional Animal Care and Use Committee assurance (Protocol #08-48) was obtained for the handling and sacrifice of inconnu within the Sulukna River. To ensure that sampled inconnu were part of the spawning population, sampling took place in September and early October in all years. In 2007 and 2008, 142 inconnu were collected by hook-and-line methods from pool habitats adjacent to the spawning grounds during the spawning period. Approximately equal numbers of male and female inconnu were collected for aging. Inconnu were collected in 2008 (n = 32) and 2009 (n = 68) with a monofilament gill net that was 15 m long and 2 m deep, with 10-cm stretch-mesh webbing placed in a pool adjacent to the sonar site. Post-spawning fish were captured as they migrated downstream past the sonar site. In addition, I collected 109 pre-spawning inconnu in the lower Sulukna River in mid-September of 2009 with hook-and-line sampling methods in pool habitats. The fork length of each fish was recorded to the nearest mm. Hander et al. (2008) presented length distribution data from three inconnu spawning populations showing that males were smaller on average than females. I used a Kolmogorov-Smirnov test of the null hypothesis that length distributions of male and female inconnu from the Sulukna River population were equal versus the alternative one-tailed hypotheses that the male length distribution was shifted smaller than the female length distribution. I used one-way ANOVA, grouping information using the Tukey method, to compare the length distributions of male and female inconnu from spawning populations of inconnu from the Kobuk, Selawik, Yukon, and Sulukna rivers. I tested the null hypothesis that the length distributions for male and female inconnu were similar between populations versus the alternative two-tailed hypothesis that that they would be different. Using a gill net, the ninety-seven fish collected at the sonar site were each weighed on a digital scale to the nearest gram. To prevent repeat sampling of inconnu that were captured and released, a fin clip was taken from the right pelvic fin.

Sex was determined by several different methods. For fish adjacent to the spawning grounds and in the lower Sulukna River, sex was determined by the release of milt or eggs with pressure to the abdomen. If no eggs or milt were released, the sex of the fish was determined by the relative distention of the abdomen by two observers. This method has been demonstrated to be a reliable method of sex determination for mature, pre-spawning inconnu (Brown 2000). Ninety-eight fish at the sonar site were sacrificed for otolith removal, and sex was determined once those fish were eviscerated. Past studies presented feeding data from spawning inconnu populations showing that food was absent in inconnu prior to spawning (Alt 1969a; Brown 2000). The feeding condition of each of the sacrificed fish was assessed by examination of the stomach. Food was noted as either present or absent.

I collected sagittal otoliths from 48 male and 50 female inconnu (32 in 2008 and 66 in 2009). Otoliths were removed via the "open hatch method" (Secor et al. 1991). A dorso-ventral transverse cut was made just posterior to the occipital bone. The cut continued ventrally to the position parallel to the dorsal margin of the orbit. Another cut continued to a cranio-caudal frontal cut along the dorsal margin of the orbit continuing to the transverse cut, thus exposing the brain. Once the brain was removed, the sagittal otoliths were located and removed with forceps. The otoliths were cleaned by rubbing them between two fingers until all tissue and blood were removed, and they were then placed in a small envelope and stored. One otolith from each fish was thin sectioned in the transverse plane through the core and mounted on a glass slide using thermal glue. Each section was approximately 0.3 mm thick, and growth increments were visible with transmitted light when viewed through a microscope. Otoliths that were selected for chemical analysis were polished with 1-um diamond abrasive and coated with a thin layer of conductive carbon. Inconnu collected by hook-and-line sampling were released back into the Sulukna River once sampling was completed. Carcasses of sacrificed inconnu were returned to the Sulukna River in accordance with the ADF&G collection permit (ADF&G permit # SF2008-178 and SF2009-190) stipulations. I used a Mann-Whitney test to determine if the median ages of male and female inconnu were significantly different within the Sulukna River spawning population. The null hypothesis was that the median ages of male and female inconnu were similar versus the alternative hypothesis that that they were different.

2.2.2 Otolith chemistry

I chose a sample size of 12 fish for chemical analyses because Brown (2006) showed that for a sample size of 12 there was a probability greater than 97% of selecting at least one anadromous fish when the actual proportion of anadromous fish in the population was 0.3. Thin-sectioned otoliths from six male and six female inconnu were selected for chemical analysis using a stratified, random sampling procedure. Inconnu were stratified into four age groups: 9-11 years old; 12-14 years old; 15-19 years old; and those greater than 20 years old. One male and one female inconnu were randomly selected from the two younger age groups, and two male and two female inconnu were randomly selected from the two older age groups. To determine frequency of migrations to salt water over an inconnu's lifetime, more inconnu were selected from the older age classes based on the assumption that older inconnu would have a higher probability of making multiple migrations to salt water.

Otolith chemical analyses were conducted using a WD-EM (Cameca SX-50) located at the Advanced Instrumentation Laboratory, University of Alaska Fairbanks. Strontium and Ca X-ray counts were collected along a core-to-margin transect for each otolith avoiding any irregularities, such as cracks, which could alter the electron beam. The electron beam conditions were set to 15 kilo-electron volts (keV), with a current of 20 nanoamps (nA) and a 5-µm diameter. Center-to-center distance between points was 8 µm, with a count time of 25 s at each point. These X-ray counts were standardized to counts per second per nanoampere (counts $\cdot$ s^{-1} $\cdot$ nA^{-1}). Conversion factors between X-ray counts and elemental concentration estimates in $mg \cdot kg^{-1}$ were determined by using established quantitative procedures on strontianite and calcite standards as outlined by Brown et al. (2007). Elemental molar concentrations were determined by using equivalencies outlined by Brown and Severin (2009) where:

$$\left(\frac{Sr_{moles}}{kg}\right) = \left(\frac{Sr_{mg}}{kg}\right)\left(\frac{1_{mole}}{87.620_{g}}\right)\left(\frac{1_{g}}{1000_{mg}}\right)$$

and

$$\left(\frac{Ca_{moles}}{kg}\right) = \left(\frac{Ca_{mg}}{kg}\right)\left(\frac{1_{mole}}{40.078_{g}}\right)\left(\frac{1_{g}}{1000_{mg}}\right).$$

I measured maximum Sr:Ca ratios for each otolith along with Sr variability. I measured variability within the sampled otoliths by using an index of the coefficient of variation (CV) of the Sr X-ray count data. The CV is a function of Sr X-ray counts at each sample point on the core-to-margin transect relative to the mean value (CV = SD • mean^{-1} • 100). The index of the coefficient of variation (CVI) was calculated as:

CVI = (actual CV of Sr X-ray counts)/(expected CV of Sr X-ray counts).

The CVI allows for the comparison of the expected CV versus the actual CV. A chemically homogeneous sample would have a CVI of 1 and chemically heterogeneous sample would have a CVI greater than 1. Yet in otoliths, factors such as water temperature, salinity, and growth rates can affect the rate of deposition of elements (Kalish 1991; Radtke and Shafer 1992), so the CVI of an non-amphidromous fish should be slightly higher than 1, and the CVI of an amphidromous inconnu would be much higher than 1.

I empirically established critical point criteria for the life history classification as amphidromous or non-amphidromous by plotting maximum Sr:Ca level and CVI data from five fish of known amphidromous origin and five fish of known non-amphidromous origin on a scatterplot. Amphidromous fish included Bering cisco *C. laurettae* and broad whitefish *C. nasus*. Non-amphidromous fish included kokanee *O. nerka*, Arctic grayling, lake trout *Salvelinus namaycush*, humpback whitefish, and broad whitefish. Chemical analyses were performed on one otolith from each fish. Amphidromous fish had maximum Sr:Ca values from 3.3 to 16.2 and CVI values from 4.7 to 37.2. Non-amphidromous fishes had maximum Sr:Ca values from 0.6 to 1.82 and CVI values from

1.04 to 1.69. Based on these data, an inconnu was considered amphidromous if the maximum Sr:Ca ratio was greater than 1.9 and the CVI value was greater than 2.0, and non-amphidromous if below these values.

2.3 Results

2.3.1 Length, weight, age, and feeding

A total of 351 inconnu were collected and sampled for sex and length from the three sampling locations. Of these fish, 206 were male and 145 female. Ninety-eight fish were weighed, examined for indications of feeding, and had their sagittal otoliths removed for aging. The median length and weight were 720 mm and 3.1 kg for male and 820 mm and 4.1 kg for female inconnu (Table 2.1). Length-frequency distributions were significantly different between male and female inconnu with females being significantly longer than males (K-S two sample test, $P < 0.001$ (Figure 2.1)). Length histograms from four inconnu spawning populations (Kobuk River data from Alt 1969a; Yukon River data from Brown 2000; and Selawik River data from Hander et al. 2008) from which sex-specific length data were collected illustrate that the smaller length classes were dominated by male inconnu, and the larger length classes by female inconnu (Figure 2.2). The Sulukna and Yukon river populations were not significantly different from one another but both were significantly different from the Selawik and Kobuk rivers' spawning populations for both male and female inconnu (Table 2.2). The median age of males was 10 years, and for females, 14 years (Table 2.1). Males ranged from 6 to 26 years of age, while females ranged between 9 and 25 years of age (Figure 2.3). Median age of females was significantly greater than the median age of males (Mann-Whitney, $p = 0.025$). Age-at-length varied for male and female inconnu. For example, age-9 male inconnu varied in length 150 mm ranging from 630 mm to 780 mm. Female inconnu also varied in length-at-age with age-14 varying 155 mm ranging from 735 mm to 890 mm (Figure 2.4). All of the 98 inconnu examined for evidence of feeding had empty stomachs.

Table 2.1 Age, length, and weight data of sampled inconnu from the Sulukna River spawning population; values given as median and ranges.

	Age (years)	Length (mm)	Weight (kg)
Males	10 (6 - 26)	720 (620 - 840)	3.1 (2.2 - 4.2)
	(n = 48)	(n = 206)	(n = 47)
Females	14 (9 - 25)	820 (655 - 930)	4.1 (3.1 - 6.3)
	(n = 50)	(n = 145)	(n = 50)

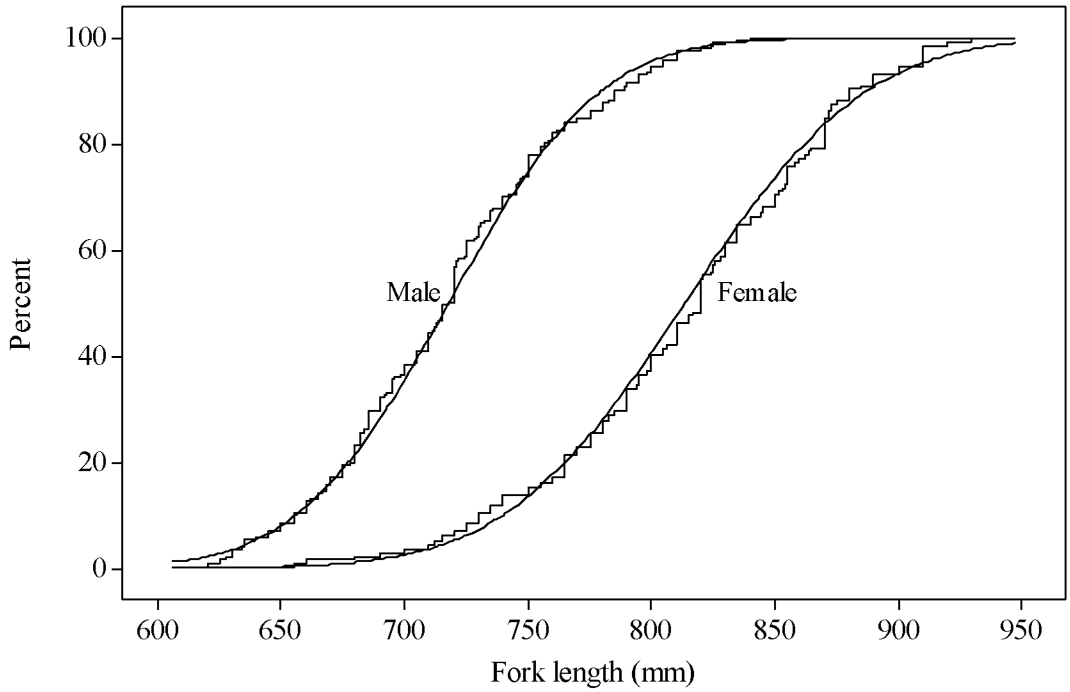

Figure 2.1 Cumulative distribution functions (original data and fitted lines) of fork lengths (mm) for mature male (n = 206) and female (n = 145) inconnu from the Sulukna River spawning population. Females were significantly longer than males (KS = 0.6528, $p < 0.001$).

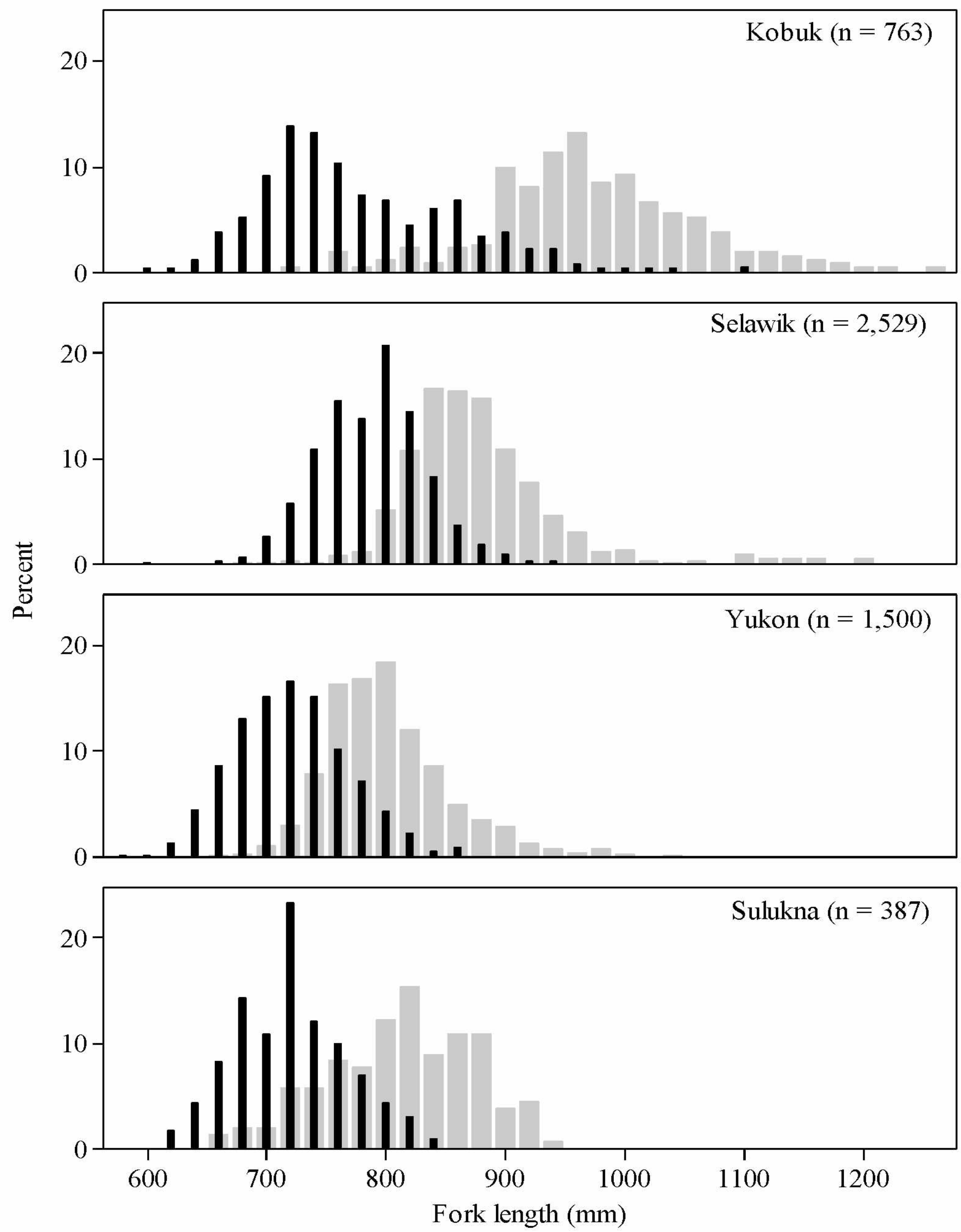

Figure 2.2 Length histograms of male (narrow, dark bars) and female (wide, light bars) inconnu from spawning populations on the Kobuk, Selawik, Yukon, and Sulukna rivers (Sources: Kobuk River data from Alt 1969a; Yukon River data from Brown 2000; and Selawik River data from Hander et al. 2008).

Table 2.2 Significant differences in length distributions of male and female inconnu from four spawning populations in Alaska, using the Tukey test for multiple comparisons of populations. Letters designate significant differences, with succession of letters denoting longer lengths (Sources: Kobuk River data from Alt 1969a; Yukon River data from Brown 2000; and Selawik River data from Hander et al. 2008).

Population	Sex	n	Mean Length (mm)	Grouping
Kobuk	Male	489	773	B
Selawik	Male	1,841	782	C
Yukon	Male	818	715	A
Sulukna	Male	231	718	A
Kobuk	Female	274	970	C
Selawik	Female	688	874	B
Yukon	Female	682	797	A
Sulukna	Female	156	809	A

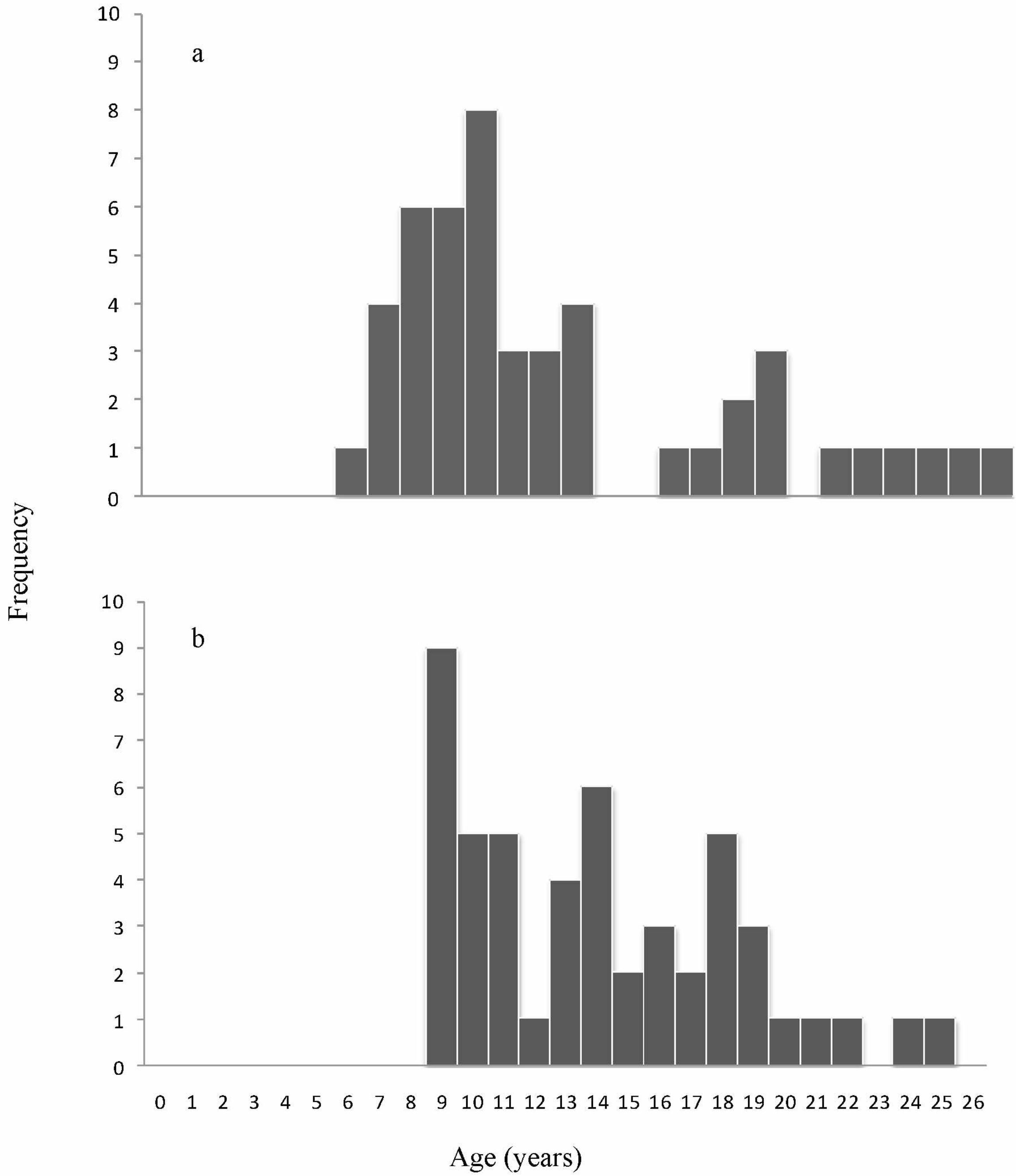

Figure 2.3 Age-frequency histogram for spawning male (a) n = 48 and female (b) n = 50 inconnu in the Sulukna River. Females were significantly older than males (Mann-Whitney ($p = 0.025$).

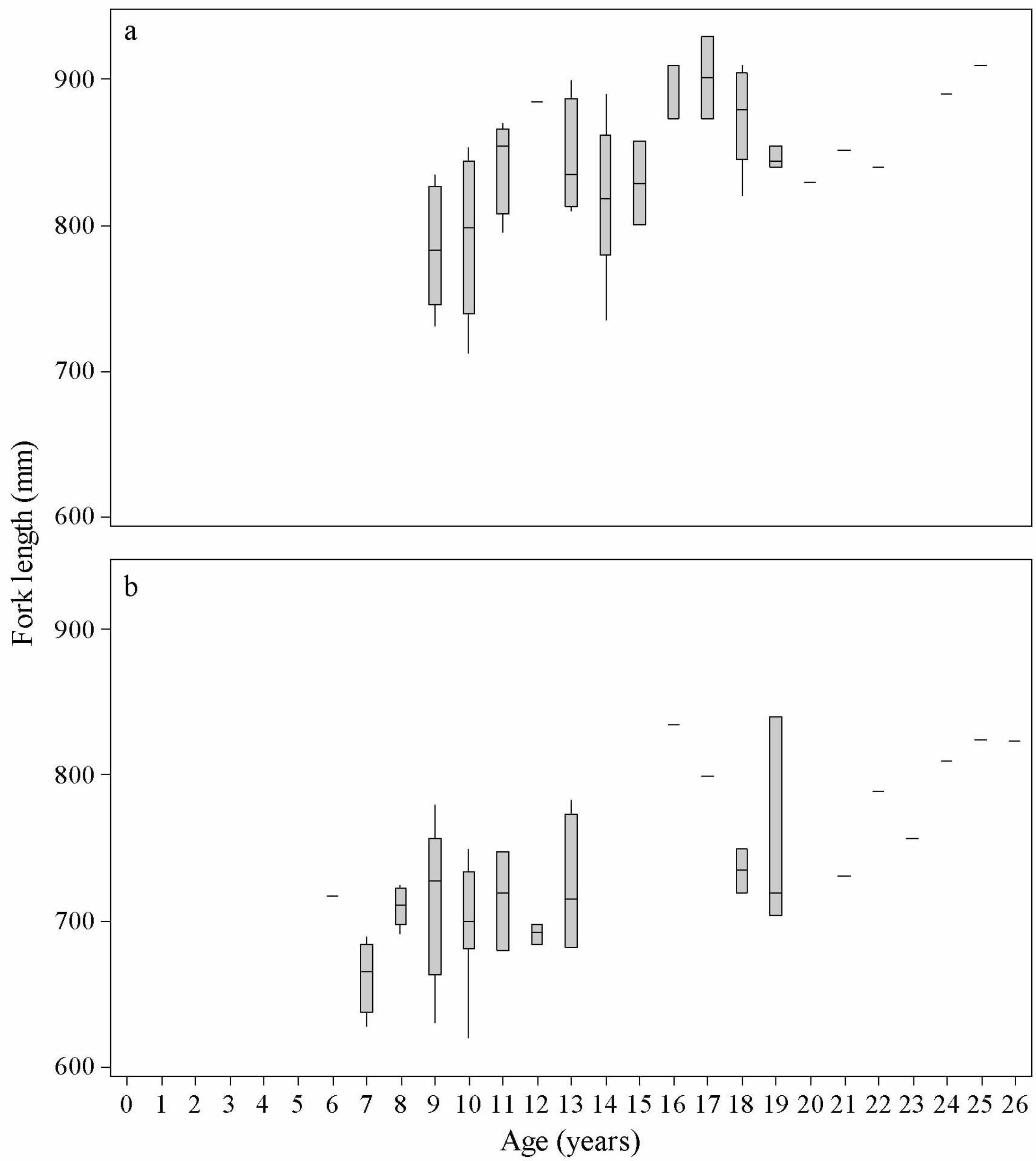

Figure 2.4 Length-at-age distribution plot for female (a) and male (b) inconnu. The plot includes median line, interquartile range box, and whiskers that encompass more than 95% of data points.

2.3.2 Otolith chemistry

Otolith Sr:Ca ratios were measured along core-to-margin transects of twelve inconnu collected from the Sulukna River in 2008 and 2009 (Figure 2.5). Of these fish, three individuals met the criteria of a maximum Sr:Ca ratio greater than 1.9 mmol:mol and a CVI greater than 2.0 and were thus classified as having an amphidromous life history (Figure 2.6). Figure 2.7 displays the strontium distribution, with ages indicated, for the three amphidromous inconnu. The first Sr:Ca peak indicating the inconnu entering a saline environment was before the age-1 annulus for one 19 year old male inconnu (Figure 2.7a), before the age-2 annulus for a 16 year old female inconnu (Figure 2.7b), and before the age-3 annulus for a 17 year old female inconnu (Figure 2.7c).

2.4 Discussion

2.4.1 Age and length distributions

The significantly different length distribution of male and female inconnu in the Sulukna River sample was similar to the results from the Yukon (Brown 2000), Kobuk (Taube and Wuttig 1998), and Selawik (Hander et al. 2008) rivers (Table 2.2). Median and maximum length for male and female inconnu sampled from the Sulukna River were also similar to those from inconnu sampled from the Yukon River (Brown 2000), but smaller than inconnu sampled in the Kobuk (Taube and Wuttig 1998) and Selawik rivers (Hander et al. 2008) (Figure 2.2). This may be a result of Kobuk and Selawik river inconnu having relatively short spawning migrations from their feeding and overwintering areas and their ability to overwinter and feed in highly productive estuarine environments.

Prior to 1997, aging of inconnu was done primarily through scale analysis. This method has been repeatedly shown to underage long-lived fishes (Taube and Wuttig 1998; Howland et al. 2004). However, since the late 1990s, a series of studies in North America have used otoliths for aging, from which comparisons to the sampled fish of Sulukna River spawning population can be made (Howland 1997; Taube and Wuttig

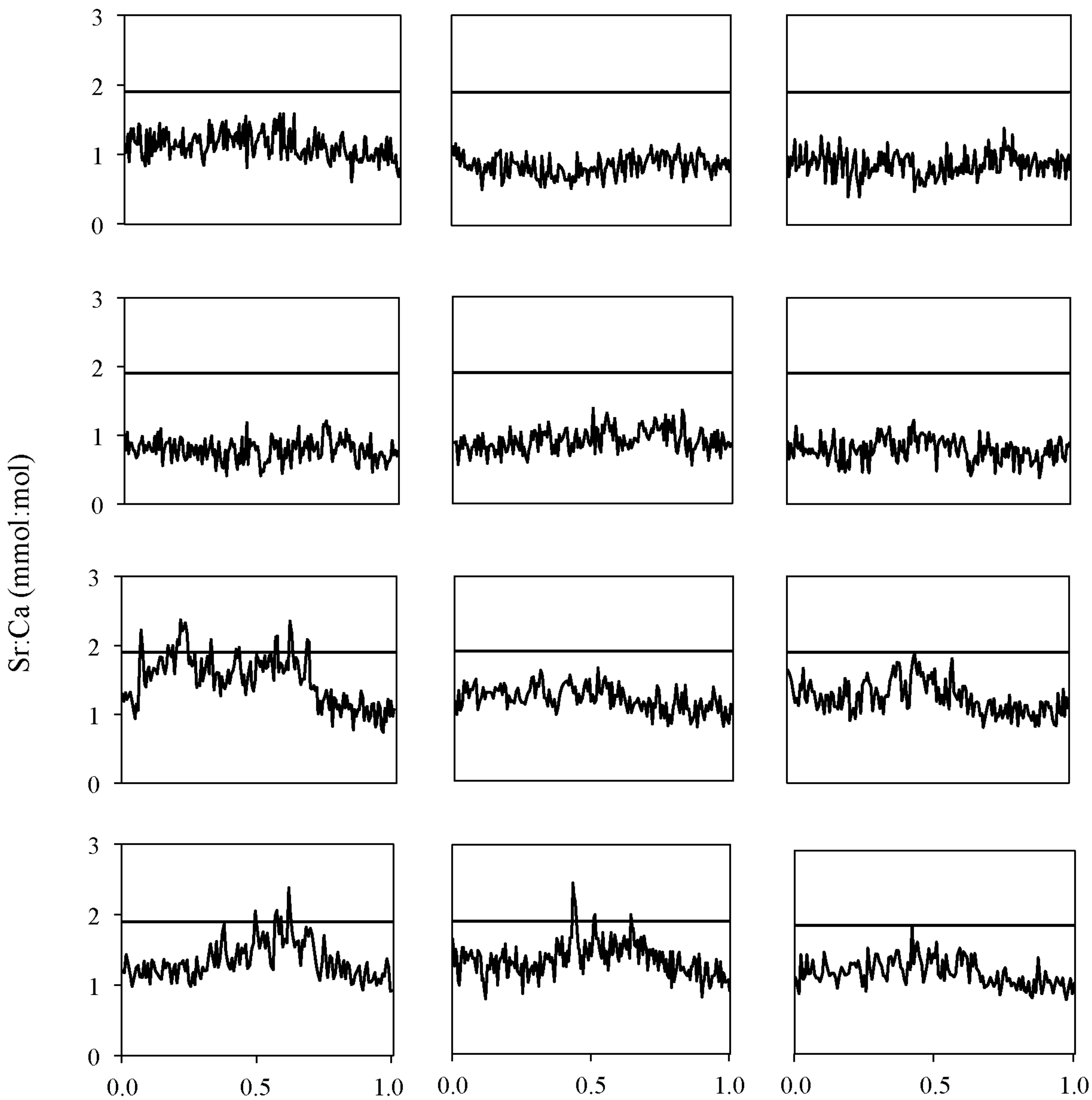

Figure 2.5 Core-to-margin strontium (Sr) graphs for twelve spawning inconnu from the Sulukna River. The dashed line indicates the 1.9 Sr:Ca mmol:mol critical point for amphidromy.

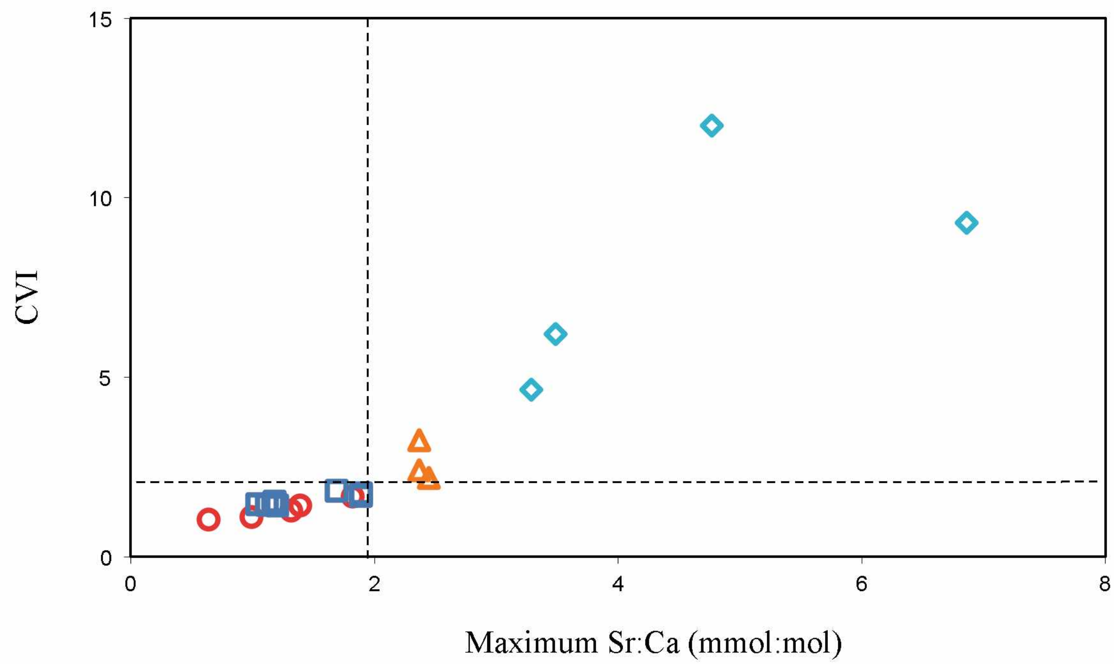

Figure 2.6 Plot of the CVI, versus the maximum Sr:Ca (mmol:mol) ratio for 4 known amphidromous (diamonds) and 5 non-amphidromous (circles) salmonid fishes. Sulukna River inconnu are displayed as amphidromous (triangles) and non-amphidromous (squares). The vertical dashed line denotes Sr:Ca ratio of 1.9 mmol:mol and the horizontal line a CVI of 2.0. Known amphidromous individual not shown on figure at 16.2 maximum Sr:Ca and 37.2 CVI.

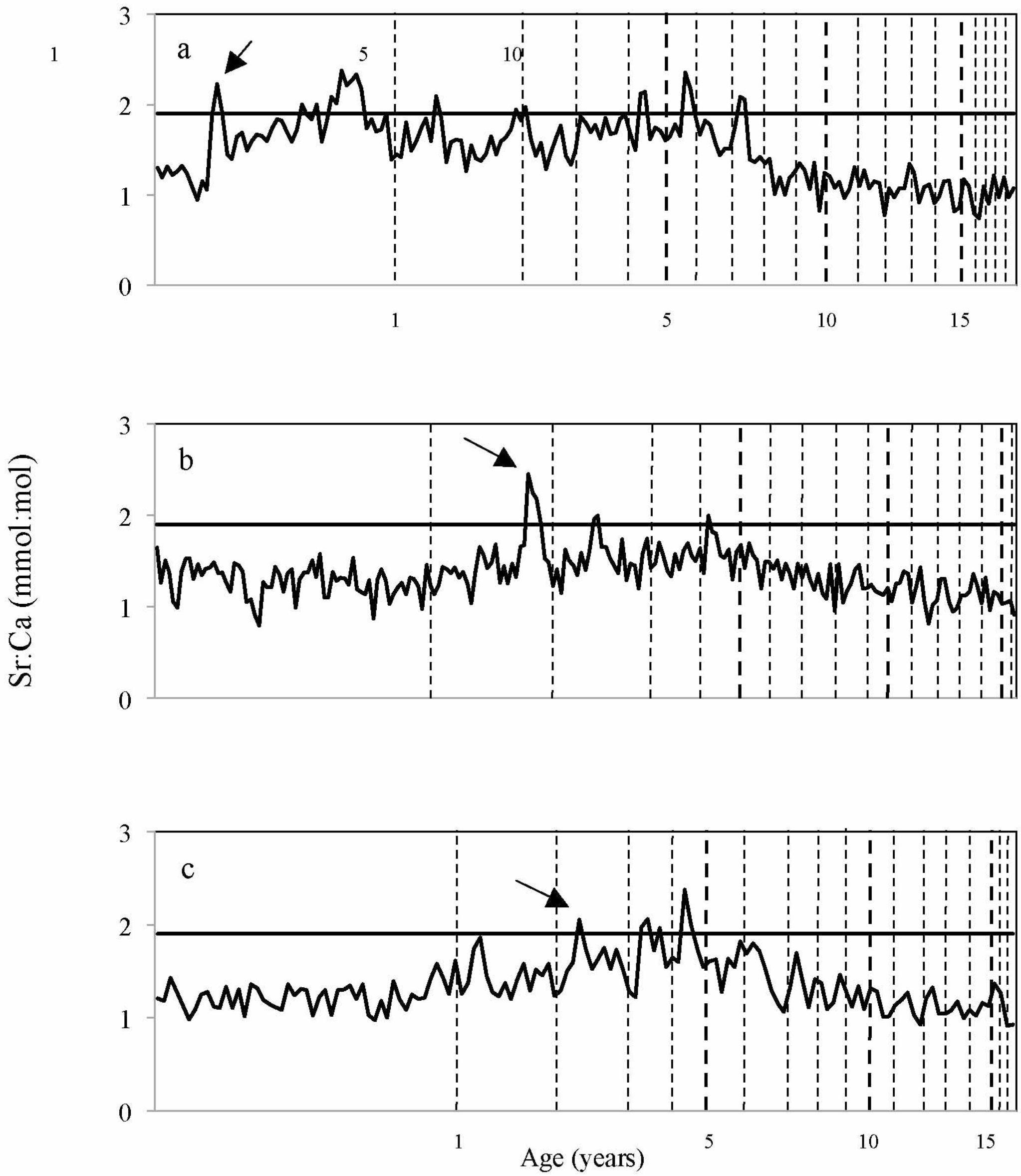

Figure 2.7 Strontium core-to-margin transects of the three amphidromous inconnu sampled. Annuli (dashed vertical lines) and the 1.9 Sr:Ca mmol:mol amphidromy critical point (dashed horizontal line) are indicated. Arrows indicate first movement into saltwater.

1998; Brown 2000; Howland et al. 2001;VanGerwen-Toyne et al. 2008). Of the sampled fish, minimum age at maturity was 6 years for males and 9 years for females. This is consistent with other inconnu populations where males tend to reach maturity earlier than females (Taube and Wuttig 1998; Brown 2000). A maximum age estimate of 26 years for the Sulukna River fish was similar to those of other spawning populations within Alaska, 27 years in the Kobuk (Taube and Wuttig 1998) and Yukon rivers (Brown 2000) populations, yet less than those found in tributaries to the Mackenzie River system, 37 years in the Peel River (VanGerwen-Toyne et al. 2008) and 31 years old in the Arctic Red River (Howland et al. 2001) populations. The age distributions for the sampled inconnu were dominated by ages 7 to 13 for males (71%) and ages 9 to 14 for females (60%). This may be a reflection that a large percentage of these younger age class fish are first time spawners with older age classes being under represented due to skip-year or greater spawning frequency. Both sexes had a large percentage of sampled fish (10% male and 16% female) from ages 18 to 19, which may indicate a significant recruitment event, similar to that described by Hander et al. (2008). Length-at-age data from studies within Alaska indicate that variation of length at a given age has been shown to vary substantially within coregonid populations (Brown 2000; Carter 2010). Within the sample of Sulukna River inconnu, length-at-age varied up to 150 mm for males and 155 mm for females. These differences could be attributed to differences in feeding and migration patterns. Inconnu are highly migratory, with some individuals migrating to salt water while others do not. Therefore, inconnu growth rates would vary greatly based on the energetic costs associated with migrations, environmental conditions experienced when feeding, and the quality and quantity of forage found. These conditions most likely explain the large differences in length-at-age documented here.

2.4.2 Otolith chemistry

The otolith chemistry from three of the twelve otoliths from sampled inconnu in this study indicated migrations to the sea. Amphidromous inconnu must migrate over 1,300 km from estuarine habitats of the lower Yukon River to the spawning area in the Sulukna

River. This migration is substantial yet less than the 1,700 km migration of inconnu sampled from the Yukon River spawning population (Brown et al. 2007) and 1,800 km of individuals collected from the Liard River (Stephenson et al. 2005). The small sample size from this study and Brown et al.'s (2007) work limit our ability to make population-level inferences based on the results. The degree of amphidromy within a population of inconnu has been shown to vary with the location of sampling (Brown et al. 2007). Within the Yukon River system, inconnu collected from locations of over 2,000 km from the sea showed no signs of amphidromy (Brown et al. 2007). This indicates that distance from the spawning area to the ocean does have an impact on whether an inconnu population has amphidromous individuals or not. However, under this amphidromy/non-amphidromy distance threshold distance to sea does not appear determine the degree of amphidromy within that population. Some of the most distant collection locations, containing amphidromous individuals, had the largest proportion of sample being amphidromous (Brown et al. 2007).

The Sr:Ca profile for non-amphidromous individuals showed low level and low variation profiles from the otolith core-to-margin. These results are similar to non-amphidromous inconnu found in other systems (Howland 1997; Brown 2000). The low levels of the Sr:Ca ratio reflect the low Sr concentrations in the freshwater environment of the Yukon River where Sr:Ca ratios are approximately 2 mmol:mol in comparison to the approximately 8.61 mmol:mol Sr:Ca ratio found in a marine environment (Brown and Severin 2009). The relatively flat profile indicates stable Sr levels in the fish's environment indicating a minimal change in the inconnu's freshwater environment. Small changes in the ratio of Sr:Ca were evident in the profiles and are likely the result of seasonal changes including water temperature (Mugiya and Tanaka 1995) and growth rate (Sadovy and Severin 1994), which can affect uptake and incorporation of Sr in otoliths. These changes are minor and are not thought to be significant enough to hide the effects of salinity on Sr incorporation in the otoliths (Secor et al. 1995) and thus affect determination of amphidromy.

The Sr:Ca ratio profiles for amphidromous individuals were characterized by a low and flat profile initially followed by one or more significant increases in the Sr:Ca ratio. These peaks indicated first movement into a saline environment. As mentioned previously, the first peak of the three sampled inconnu determined to be amphidromous was before the first annulus for one individual, before the second annulus for another, and before the third annulus for the final amphidromous individual. Previous chemical analysis has documented inconnu in estuarine areas in their first years of life (Howland 1997; Brown 2000). Like other whitefish species, larval dispersion occurs with spring freshets each year (Naesje and Jonsson 1986). These spring floods move larval inconnu from spawning to estuarine areas. Amphidromous individuals that did not reach salt water areas within their first year most likely spent their first years feeding in freshwater environments before moving to salt water areas by active swimming or being aided once again by spring freshets in following years. All amphidromous individuals had multiple peak Sr:Ca events exceeding the 1.9 mmol:mol critical value, indicating multiple migrations between fresh and salt water. These multiple migrations occurred on an annual basis and have also been observed in Arctic char (Babaluk et al. 1997), broad whitefish (Carter 2010), and in other inconnu populations (Howland 1997; Brown 2000). All amphidromous individuals had concluded migrations to these saline environments by age-8 when Sr profiles returned to the low level and low variation profile associated with non-amphidromous life histories. This pattern has also been observed in spawning populations of inconnu in the Arctic Red (Howland 1997) and Yukon rivers (Brown 2000) and in broad whitefish in the Yukon River (Carter 2010). It has been suggested that once the fish has reached sexual maturity they are able to sustain somatic and reproductive demands in the freshwater environment without returning to saline environments (Carter 2010).

Both amphidromous and non-amphidromous individuals were sampled from the Sulukna River spawning population with each amphidromous individual exhibiting a different migration pattern. This is evidence that amphidromy is not obligatory but facultative within the population. Facultative amphidromy is when a fish will migrate to saline areas when environmental conditions are favorable or when energetic constraints compel it to do so (Gross et al. 1988; Babaluk et al. 2002). These conditions may include increased food availability, decreased predation, decreased disease, or decreased physiological stress (Gross et al. 1988). However, information regarding these conditions for juvenile inconnu and how they vary among populations is currently lacking. This limits our ability to make inferences to what conditions are driving amphidromy in inconnu. Only when future research addresses these data gaps will we understand not only what is causing individuals from these populations to migrate, but also how and why it varies between and among these populations.

3.0 Abundance and migration timing

3.1 Introduction

Inconnu populations exhibit complex and variable patterns of migration and reproduction, making them challenging to monitor and manage. For example, both amphidromous and potamodromous spawning populations were found within the Mackenzie River system (Howland et al. 2001). On the Kobuk and Selawik rivers it has been suggested that both sequential and skip-year spawning occurred based on sequential-year capture of fish in mark-recapture studies (Taube 1997; Underwood 2000). With both amphidromous and potamodromous life history strategies, mixing of spawning populations in feeding areas, and the large geographic area inconnu inhabit, absolute population estimates are impractical (Underwood 2000). Due to these complexities, monitoring of inconnu spawning population abundance has been used as an index of total population abundance (Taube 1996, 1997; Taube and Wuttig 1998; Underwood 2000; Hander et al. 2008). Accurate abundance estimates from spawning tributaries are an important fisheries management tool used to assist in the determination of production, survival, harvest, and spawner-recruit relationships (Neilson and Green 1981; Labelle 1994).

Few studies in North America have attempted to estimate inconnu spawning population abundance. The Chatanika (Alt 1969b; Kepler 1973), Kobuk (Taube 1996, 1997; Taube and Wuttig 1998), and Selawik (Underwood 2000; Hander et al. 2008) rivers in Alaska are the only three systems in North America that have had accurate abundance estimates performed on spawning populations of inconnu. These assessments demonstrate a great deal of inter-annual variability in abundance for these populations. The mark-recapture methods used for the abundance estimates were often accompanied by large confidence intervals. These large confidence intervals often occur with large inconnu abundances, which require large sample sizes of tagged fish. An assessment of abundance on the Kobuk River in 1996 documented an estimated abundance of 43,036 inconnu with 90% confidence intervals of 25,241 – 60,831 (Taube 1997). In the Selawik River in 2005 an estimated inconnu abundance of 46,324 inconnu with 95% confidence intervals of 25,069 – 67,580 was documented (Hander et al. 2008). This complicates a manager's ability to make informed management decisions in regard to the spawning population or the population as a whole. This project was designed to obtain a more precise estimate of spawning population using sonar.

A spawning population of inconnu was discovered in the Sulukna River drainage in the mid-1980s (Alt 1985). The discovery led to other investigations that have provided some information on migration and spawning timing, defined the spawning reach, and described spawning habitat qualities. The U.S. Fish and Wildlife Service, Alaska Department of Fish and Game, BLM, and Tanana Chiefs Conference conducted an inconnu radio telemetry study beginning in 2003. This telemetry work conducted from 2003 to 2008 on the Sulukna River indicated that by September and October inconnu were located in areas 25 to 92 rkm upstream in the river with the largest concentrations between rkm 72 and 92. Telemetry data from 2003 indicated that the majority of inconnu tagged in the lower Sulukna River in early September had migrated downstream past a tower on the Nowitna River between September 30 and October 4. Inconnu were found to overwinter in a large geographic area of the Yukon River (R. Brown, USFWS, personal communication). Inconnu were found spawning in run habitats in a narrow reach of approximately 20 km which was located between rkm 72 and 92 (Gerken 2009). Spawning habitat occurred in areas with substrate between 6 and 12 cm, a width to depth ratio between 15 and 36, and water conductivity between 266 and 298 μS/cm. No information on spawning population abundance was available prior to this study.

Side-scanning sonar technologies are often the only effective method of counting fish in locations where water conditions are too turbid for visual enumeration (Dunbar 2001). However, these technologies have historically been poor at differentiating between species (Burwen et al. 2007). Recently, a Dual frequency IDenification SONar (DIDSON) was developed by the University of Washington's applied physics lab. This acoustic camera has many advantages over traditional sonar. These advantages include: easy-to-detect images of fish, a wider viewing angle, better coverage of the water column, simpler aiming and operation, accurate upstream-downstream target resolution, background subtraction feature, less multi-pathing, and reasonable measures of fish length obtainable out to 21 m in the river channel (Maxwell and Gove 2004; Burwen et al. 2010). Species differentiation is now possible by using length apportionment or other methods (Burwen et al. 2007; Mueller et al. 2010). Given these technological advances, DIDSON appeared to be the ideal tool to estimate the abundance and determine the post-spawning migration timing of inconnu populations in small watersheds like the Sulukna River, provided there were few or no other species of a similar size migrating downstream with them.

The main objectives of this component of the study were to estimate the spawning population abundance and document the post-spawning migration timing of inconnu in the Sulukna River using a DIDSON system. A third objective was to examine variation in sex composition throughout the post-spawning migration based on sampling data.

3.2 Methods

3.2.1 Hydroacoustic equipment

A US300 DIDSON unit (Sound Metrics Corporation, Lake Forest Park, Washington) was used to monitor the post-spawning migration of inconnu in the Sulukna River (Belcher et al. 2001). The DIDSON operated at 1.8 MHz (high frequency) for observations less than 12 m from the transducer and 1.0 MHz (low frequency) for distances up to 30 m. Beam dimensions were 29° in the horizontal axis and 12° on the vertical axis. The horizontal beam width of the high frequency setting was comprised of 96 beams 0.3° wide and 48 beams 0.6° wide for low frequency. Frame rates varied from 6-8 frames • s^{-1}. Data was output to a laptop computer and external hard drives for storage.

3.2.2 Site selection and transducer deployment

I originally selected the DIDSON location during a site visit in July 2007. The streambed had a gradual sloping cross section between the gravel bar, where the DIDSON unit would be deployed, to the cut bank on the opposite side of the river, providing a smooth substrate on which to deploy the DIDSON unit. I reevaluated the DIDSON location in 2008 from channel cross-sectional river profiles defined using the DIDSON unit. Irregularities that would allow fish to pass undetected were identified by running several cross-sections along the selected site. Artificial targets were deployed throughout the ensonified zone on the river bottom and throughout the water column at various distances from the DIDSON. From these analyses, I determined that the bottom profile at one site was adequate and that no fish could pass the unit undetected. Once the site was selected, the transducer was attached to an aluminum tripod and installed 15 m from the east bank and aimed perpendicular to river flow. A 16 m long, 1 m tall vexar fence with 3-cm mesh was installed from the gravel bar to 1 m past and 1 m upstream of the DIDSON unit, which prevented any downstream moving fish from avoiding the ensonified area (Figure 3.1).

3.2.3 Data acquisition and processing

Abundance and migration timing data were collected continuously, 24 hours a day, 7 days a week, in 60-minute sample periods, and saved to an external hard disk drive. Daily counting periods were defined as beginning at 1200 hours and ending at 1200 hours on sequential days. These data were then downloaded to a laptop computer and analyzed at the field camp, using echogram view in the DIDSON control and display software (version 5.17). Post-spawning inconnu migrating downstream past the DIDSON site were counted by marking each fish track using the DIDSON echogram. For each fish, the direction of travel was identified and the length was measured using the DIDSON video feature (Figure 3.2). Any target over 0.6 m was considered to be an inconnu. These data were tallied and exported to ASCII files. Initial enumeration and adjustments were made in the field and reanalyzed post-season.

Figure 3.1 DIDSON location on the Sulukna River.

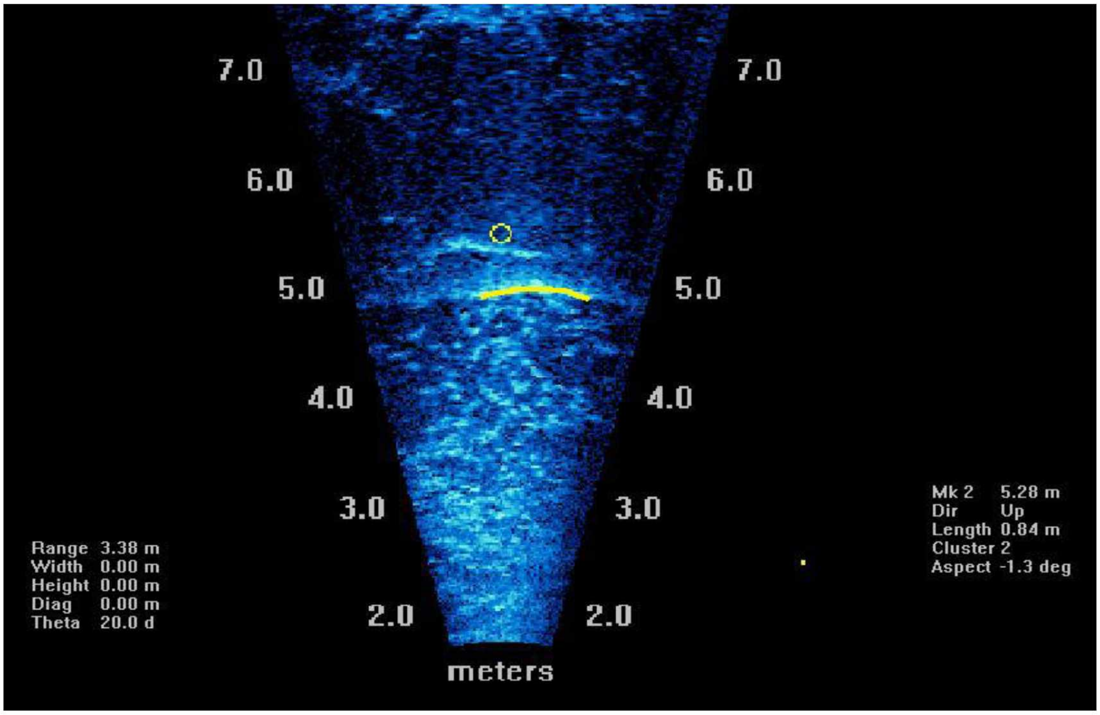

Figure 3.2 Length measurement of inconnu using DIDSON video feature.

3.2.4 Missing data

Equipment maintenance, adjustment, and malfunctions resulted in portions of hourly counts being missed. Different methodologies were used to make up for missed counts based on the amount of time missed. Partial hourly counts ($\geq$ 15 and < 60 min) were standardized to 1h, using

$$E_h = (60 / M_c) \bullet C_h ,$$

where E_h = estimated hourly downriver count for hour h, M_c = number of minutes of the hour that were counted, and C_h = downriver count during the sampled time in hour h. Counts for hours with < 15 minutes were discarded and treated as missing hours. When counting was suspended for more than 60 minutes, data for the missing time period was interpolated by averaging counts from the same time period on the day before and the day after the missed hourly count using:

$$E_d = (E_b + E_a)/2 ,$$

where E_d = downriver fish count for missing time period d, E_b = downriver count from the same time period of the previous day, E_a = downriver count from the same time period of the next day.

3.2.5 Species verification and sex ratio

It is challenging to distinguish between species with a DIDSON system even when using the high-frequency setting (Burwen et al. 2007). To ensure that images being recorded and identified as inconnu by the DIDSON unit were actually inconnu, an alternate method of sampling was used for verification. Prior to sampling, a University of Alaska Fairbanks Institutional Animal Care and Use Committee assurance (Protocol #08-48) was obtained for the handling of inconnu within the Sulukna River. A gill net sampling program was initiated to capture large (> 0.5 m) fish migrating downstream past the DIDSON location that might be incorrectly identified as inconnu. To accomplish this goal, I sampled each day during high migration periods between 2200 and 2300 hours, or until 20 inconnu were captured, with a monofilament gill net 15 m long and 2 m deep, with 14-cm mesh. The gill net was set just downstream from the DIDSON site. Fish migrating downstream through the DIDSON ensonified area were subsequently captured in the gill net. All captured fish were identified to species and sex (see methods in chapter 2) and released. Comparisons were then made between the target passing the DIDSON and the captured fish. If large fish (> 0.5 m) other than inconnu were captured, a larger sample size would be implemented for species apportionment.

3.3 Results

3.3.1 Abundance and migration timing

2008

From September 17 to October 10, 2008, 2,079 inconnu were counted migrating downstream past the DIDSON site, with 81% passing during the last nine days (Figure 3.3). Counting was suspended on October 10 due to slush ice flows and ice accumulating on the DIDSON, which made counting impossible. The downstream migration displayed a uni-modal distribution, with the peak downstream migration occurring on October 3 (n = 479). Downstream migrating inconnu displayed a nocturnal migration pattern, with 96% of fish migrating between 2000 and 0900 hours daily (Figure 3.4).

2009

From September 19 to October 8, 2009, 3,531 inconnu were counted migrating downstream past the DIDSON site, with 90% migrating during the last nine days (Figure 3.3). Counting was suspended on October 8 due to high flow conditions which made counting impossible. The downstream migration displayed a uni-modal distribution, with the peak migration occurring on October 5 (n = 1,213). Downstream migrating inconnu displayed a nocturnal migration pattern, with 96% of fish migrating between 2000 and 0900 hours daily (Figure 3.4).

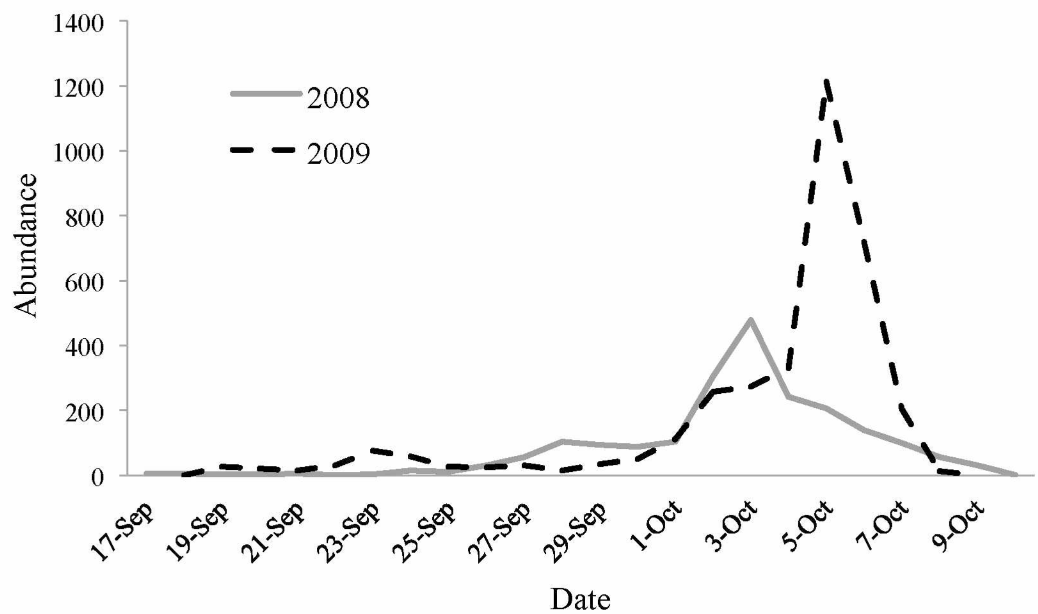

Figure 3.3 Daily abundance for the inconnu downstream migration in 2008 and 2009 in the Sulukna River, Alaska.

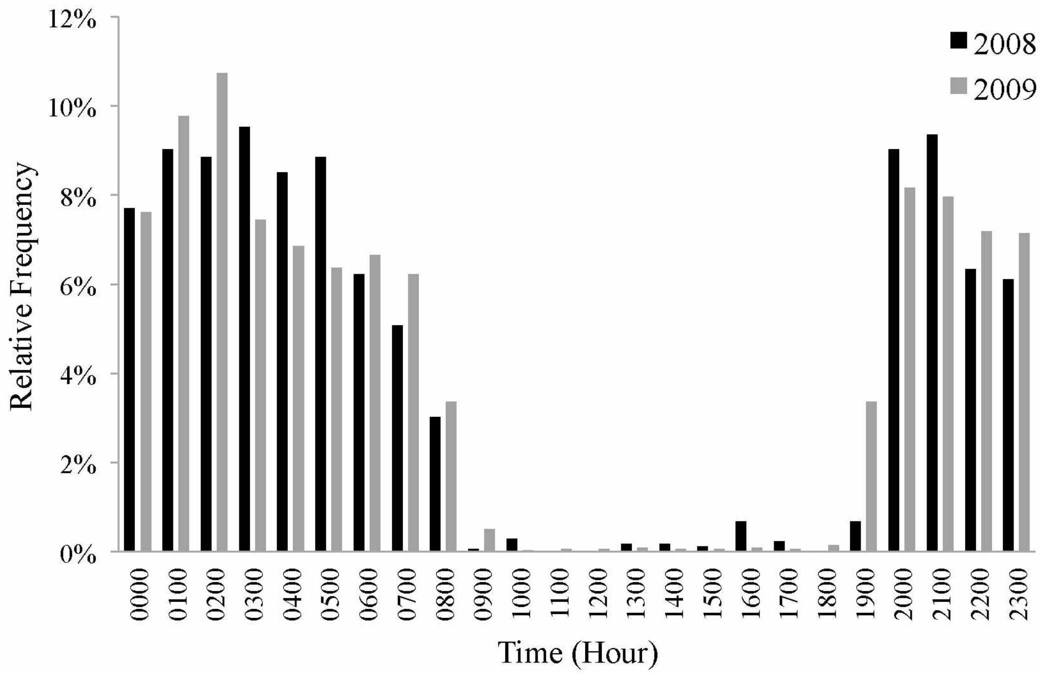

Figure 3.4 Relative frequency of hourly inconnu downstream migration in 2008 and 2009 in the Sulukna River, Alaska.

3.3.2 Missed counts and DIDSON counting conditions

A total of 6.0 hours (1.0%) in 2008 and 3.8 hours (0.8%) in 2009 were missed because of changing of hard drives, maintenance, or moving of the transducer. The counting conditions were good except for two short periods in 2008 and one in 2009. On September 30, 2008, air temperature dropped to -20°C creating ice flow in the river. The DIDSON was lowered so that the beam was under the ice and counting was resumed. On October 9, 2008, temperatures dropped to -22°C, at which point the Sulukna River became locked in ice and the DIDSON unit itself began to accumulate ice. In that case, counting operations were suspended. When counting was resumed, stranded inconnu could be seen milling in the open water reach that contained the transducer. The river remained locked in ice such that inconnu could not migrate downstream until the project was completed on October 12. On October 7, 2009, a flood event occurred. The transducer was moved back and the fence was removed. To compensate for the longer ensonified area the DIDSON unit was switched to low frequency mode. Changing of hard drives, maintenance, and icing events all occurred during periods when inconnu migration was minimal. The results presented here are thought to be nearly complete counts of inconnu abundance.

3.3.3 Species verification and sex ratio

In both 2008 and 2009, test netting data demonstrated that 100% of the fish identified as potential inconnu were indeed migrating inconnu. All fish sampled were mature with milt or eggs being expelled with pressure to the abdomen. Females comprised 40% and 39% of the cumulative samples in 2008 and 2009 respectively. The daily sex ratio for sampled inconnu in both years was dominated by females initially, and then males as the post-spawning migration progressed (Figure 3.5).

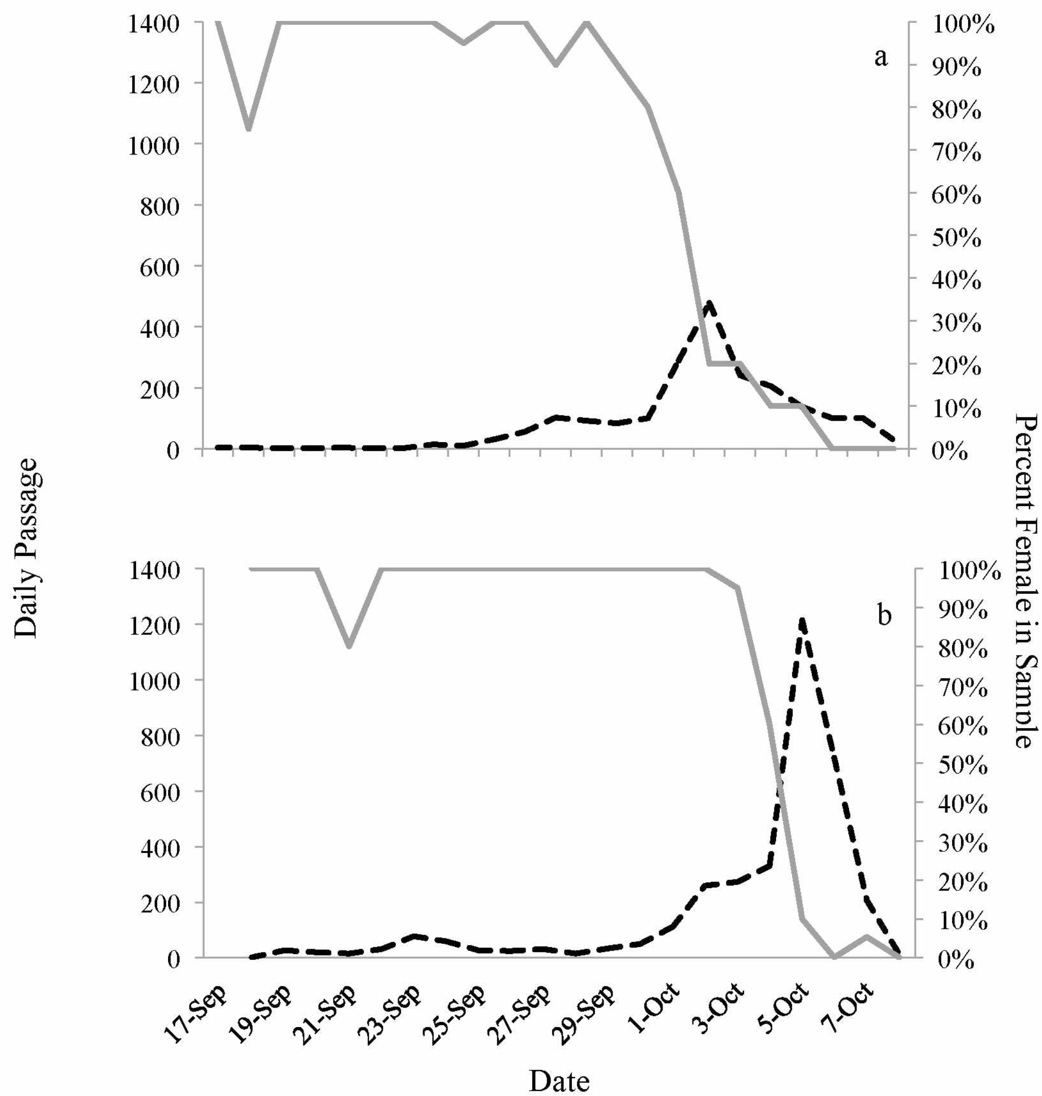

Figure 3.5 Daily passage (dashed line) and percent female in daily sample (solid line) of inconnu migrating downstream past the DIDSON site in 2008 (a) and 2009 (b) in the Sulukna River, Alaska.

3.4 Discussion

3.4.1 Inconnu abundance

The Sulukna River abundance estimates are the first true censuses of an inconnu spawning population. Mark-recapture methods have been used to estimate inconnu spawning population abundance in three rivers within Alaska. In the Chatanika River, a tributary stream in the Tanana River drainage, Alt (1969b) estimated a spawning population of 73 inconnu in 1968 and Kepler (1973) estimated a spawning population of 75 to 100 inconnu in 1972. Simple Peterson mark and recapture methods were used to generate these estimates. An assumption for this type of estimate is that the population is closed (Schnabel 1938). Kepler (1973) noted the assumptions of his estimate were not met due to the possibility of movement of fish between pools. Therefore, the estimate represents only relative numbers of inconnu present. More robust analytical methods have been employed to produce a series of abundance estimates of inconnu spawning populations on the Selawik and Kobuk rivers in northwest Alaska. Past studies have estimated from 5,990 to 46,324 spawning inconnu in the Selawik River between 1995 and 2005 (Underwood 2000; Hander et al. 2008), and estimated from 32,273 to 43,036 spawning inconnu in the Kobuk River between 1995 and 1997 (Taube 1996, 1997; Taube and Wuttig 1998). The Kobuk and Selawik river studies displayed a great deal of inter-annual variability in abundance with significant increases in relatively short time periods (Hander et al. 2008). It has been suggested this variability in abundance is due to episodic recruitment events influenced by environmental conditions (Decicco 2006; Hander et al. 2008). When favorable environmental conditions develop in concert with the large absolute fecundity of inconnu females, rapid and large changes in abundance can occur. Due to this occurrence, the abundance of inconnu in the Sulukna River in 2008 and 2009 is unlikely to reflect the minimum or maximum abundance of this spawning population and thus warrants long-term monitoring.

Previous studies, such as those on the Kobuk and Selawik rivers, calculated low precision abundance estimates, so determination of small-scale trends abundance would not be possible (Hander et al. 2008). In the Sulukna River, the DIDSON sonar system, allowed for a degree of accuracy and precision that cannot be obtained through the use of mark-recapture methods. This precision is the result of the ability to correctly identify all targets as inconnu. Sampling of inconnu by hook-and-line and gill nets confirmed that no inconnu were smaller than the 0.6-m designation for the lower limit for classification as inconnu. In watersheds where other species of fish of a similar size were present and migrating downstream, species apportionment would be required thus reducing the overall accuracy and precision of the abundance estimate.

Migration counts in this study are thought to be complete and comprised entirely of spawning inconnu. The DIDSON was operated until no additional inconnu were observed migrating downstream. A small number of inconnu may not have been counted in 2008 due to ice formation in the river. In 2008, the river became locked in ice and stranded fish could be seen milling in front of the DIDSON. This may have led to inconnu becoming trapped within the Sulukna River for the winter resulting in some level of spawning related mortality. Gonad analysis on 98 inconnu sacrificed for otolith removal indicated all were in post-spawning condition. Correctly documenting abundance and ensuring that sampled individuals are part of the spawning population will allow for small scale changes in the population to be observed and managed accordingly.

3.4.2 Migration timing

Spawning inconnu within Alaska exhibit similar life history patterns with a prolonged upstream migration to spawning areas in summer, spawning taking place in late September and early October, followed by a rapid migration downstream to overwintering areas (Alt 1977; Brown 2000; Underwood 2000). Within the Sulukna River, the timing of the post-spawning, downstream migration was consistent between years. Small numbers of downstream migrants began passing the DIDSON in mid-September with the vast majority (78% in 2008 and 89% in 2009) passing after October 1. The rapid synchronous downstream migration of post-spawning inconnu has been observed in other systems (Fuller 1955; Howland 1997). In 2009, there was a more rapid cessation to the migration than in 2008 and may be explained by the high flow conditions experienced in that year. In October of 2008, cold air temperatures caused ice formation in the river and extremely low water levels. In October of 2009, a high-flow event beginning on October 3 may have aided the inconnu downstream migration resulting in the abrupt migration of 78% of the migrating fish in the final six days.

My finding that a majority of post-spawning inconnu migrated downstream during night and early morning hours is consistent with other studies of inconnu and other coregonid species in Alaska and Canada. In 2008 and 2009, 96% of post-spawning inconnu migrated downstream past the Sulukna River DIDSON site between 2000 and 0900 hours (Figure 3.4). In the Tolovana River, a tributary to the Tanana River, upstream migration of inconnu was concentrated in early evening (Alt 1968). In the Big Buffalo River, a tributary to Great Slave Lake, while sampling individuals from the post-spawning downstream migration, the greatest numbers of fish were caught during the hours of darkness (Fuller 1955). Also, within the Sulukna River, inconnu only spawned in runs at night while occupying deep pool habitats during the day (Gerken 2009). This rapid nocturnal migration behavior has been documented for other whitefish species within Alaska. In the Chatanika River, downstream migration of humpback whitefish and least cisco *Coregonus sardinella* were concentrated in a two hour time period between 2000 and 2200 hours (Hallberg and Holmes 1987). In Whitefish Lake in Western Alaska, least cisco and humpback whitefish emigration was characterized by a large pulse after dark (Harper et al. 2007). These data suggest that nocturnal migration and other activity may be a common quality for inconnu and other coregonids everywhere.

3.4.3 Sex ratio

The inconnu captured and sampled at the DIDSON location were comprised of more males than females in both 2008 and 2009. This higher percentage of males, within a sample of a spawning population, has been observed in other inconnu spawning populations within North America (Taube 1996, 1997; Taube and Wuttig 1998; Hander et al. 2008; VanGerwen-Toyne et al. 2008). The percentage of the sampled inconnu comprised of males remained relatively constant for both years. This consistency in sex-ratio of sequential years of spawning populations has also been observed in the Selawik River (Hander et al. 2008). It has been suggested that male inconnu may be more likely to be sequential-year spawners (Taube 1997; Hander et al. 2008). Within the Kobuk River, the proportion of radio-tagged inconnu that exhibited sequential-year spawning was greater for males than females (Savereide 2010). Increased energetic demands of egg development for female inconnu, compared to males, may limit their ability to spawn on sequential years, and thus decrease the percentage of females within the spawning component of the population. Females were first to leave the spawning grounds, with males making up the majority of downstream migrants as the run progressed. This behavior has also been documented in other spawning populations of inconnu and other iteroparous salmonids. In the Big Buffalo River, larger inconnu (determined to be females based on length distribution) were caught at the beginning of the downstream migration (Fuller 1955). In Waddell Creek, California, male steelhead *O. mykiss* were the last to leave the spawning grounds (Shapovalov and Taft 1954). In the Snake River, in the northwestern United States, the downstream migration of post-spawning female steelhead composed the vast majority of the sample during the early part of the study, while the proportion of males increased as the season progressed (Evans and Beaty 2001). This behavior is most likely the result of spawning male inconnu waiting until most of the spawning females had left the spawning grounds before starting their own downstream migration. These data suggest that the sex ratios and downstream migration dominated initially by females in the Sulukna River are not unique, and may be common among all North American inconnu populations.

4.0 Conclusions

Within the Yukon River inconnu are an important subsistence and sport fish resource that is exploited throughout the watershed. Yet adequate information with which to monitor and manage the Yukon River inconnu populations does not currently exist. Effective harvest management strategies, based on the annual abundance of spawning fish, have not been developed for whitefish species within the Yukon River watershed like they have for many populations of Pacific salmon *Oncorhynchus* spp. (Brown 2006). For a management strategy to be developed for Yukon River inconnu, accurate abundance and life history traits, such as age structure and migratory patterns, must be identified and monitored over the long term.

Population abundance, biology, and migration information from this study gives us a better understanding of Yukon River inconnu. These data can be used in setting baseline levels with which to measure changes in the population. Our abundance data demonstrated that the Sulukna River population was smaller than populations in northwestern Alaska (Taube 1996, 1997; Taube and Wuttig 1998; Underwood 2000; Hander et al. 2008). The seasonal and diel timing of the downstream migration of post-spawning inconnu was similar between years. Downstream migration of inconnu was dominated by females initially then males as the migration progressed. In both years, migrating inconnu displayed a nocturnal migration pattern, with 96% migrating between 2000 and 0900 hours daily. Otolith chemistry analyses indicated that three of the twelve inconnu sampled were amphidromous. These amphidromous inconnu initially migrated to salt water areas at different ages and returned to these areas at different intervals throughout their life. This indicates that amphidromy is facultative within the population although what factors drive this are currently unknown. The migrations of the amphidromous inconnu from spawning areas in the Sulukna River to saltwater areas at the mouth of the Yukon River are over 1,300 km in length.

This study was the first to use DIDSON technology to document abundance and post-spawning downstream migration timing for inconnu. With the ability to accurately measure length of fish moving past the DIDSON site I was able to count the migrating inconnu. Apportionment of inconnu by length using DIDSON is limited in that it will not work in large rivers where the ensonified area is greater than 20 m (Burwen et al. 2010) or where species of similar size are moving downstream with inconnu. In the Sulukna River, DIDSON has proven itself to be an effective and precise tool with which to document inconnu abundance. This precision, which is absent from other abundance estimate techniques (Hander et al. 2008; Schultz et al. 1993), allows for small changes in abundance to be documented. The ability to detect these changes along with the timing of migration allows fishery and land managers to make informed decisions regarding harvest or development scenarios.

Recent work with sockeye salmon *O. nerka* in Bristol Bay, Alaska, has shown that a diversity of populations and life histories lowers variability in abundance and reduces the number of fisheries closures of the Bristol Bay stock complex (Schindeler et al. 2010). Diversity of life history traits brought on by genetic and environmental conditions may also significantly reduce the interannual variability in abundance of a single spawning population. The results from this study and others indicate that inconnu both within and between spawning populations differ in many life history traits (Howland 1997; Brown 2000). These differences, such as frequency of spawning and migration patterns, may act to buffer these populations from years of high exploitation or environmental conditions which negatively affect recruitment. With only five known spawning locations within the Yukon River watershed, priority should be given to the protection of these unique spawning sites. Currently, a portion of the Sulukna River drainage is designated as an Area of Critical Environmental Concern by the BLM, due to inconnu spawning habitat, yet this area is located downstream of the spawning grounds because the exact location was not known. This boundary should be moved to encompass all inconnu spawning areas within the watershed.

The components of this study elucidate much about the Sulukna River inconnu spawning population. Yet from each component, more questions arise from which future research can be shaped. Abundance data indicates the Sulukna River spawning population is substantial but how it compares to other Yukon River spawning populations is unknown. Abundance data from the Selawik (Hander et al. 2008) and Sulukna rivers indicate that abundance can be highly variable from year to year. How the abundance of inconnu varies over long periods and what mechanisms drive these fluctuations are still unknown. Otolith chemistry indicated that a portion of the Sulukna River population is amphidromous, with amphidromous individuals having different migration patterns. This indicates that amphidromy is facultative within this population, but what is the causing this migratory behavior? For continued sustainability and proper management of this species, future research must focus on these questions and many others.

The information provided from this study, in concert with existing information, will aid fishery managers in the development of effective harvest management strategies for inconnu. With large variation in abundance between years, continual monitoring of population abundance of spawning populations must be performed to prevent over-harvest of spawning populations in low abundance years. Also, the rapid downstream migration documented by this study demonstrates that inconnu are highly susceptible to over-harvest when moving downstream in large numbers after completion of spawning. Due to this susceptibility, fishery managers will need to adopt harvest strategies which monitor fishing activities in areas directly downstream of spawning areas and limit over-harvest during these sensitive time periods. Finally, with some Sulukna River inconnu migrating to the sea multiple times in their lifetimes, fishery managers must be cognizant of the large geographical range these fish inhabit and manage them across their range. With continued research and the adoption of these and other harvest management strategies sustainable populations of inconnu within the Yukon River can be maintained.

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